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# TECHNICAL FUNCTIONS: TOWARDS ACCEPTING DIFFERENT ENGINEERING MEANINGS WITH ONE OVERALL ACCOUNT

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## ABSTRACT

*In this paper I present an explanation of why engineers use the term function with different meanings. Then I propose an overall account of functions that accommodates a number of those meanings. In this way I define an approach towards understanding technical functions that combines elements of attempts to replace the current variety of meanings with a single meaning, with elements of attempts to tolerantly accept different meanings of technical functions. The explanation of why the term function is used with different meanings focuses on descriptions of technical devices. These descriptions can be given in an elaborated manner by using the five key-concepts of goal, action, function, behaviour and structure of devices. And descriptions of devices can be simplified by cloaking parts thereof or by bypassing in them references to some of the key-concepts, as is done in, for instance, the design methodologies of Stone and Wood, of Lind and of Gero. It is shown that in these simplifications engineers adjust the meaning of the term function in such a way that the simplified descriptions are indeed useful for engineering reasoning about devices. In the proposed overall account technical functions of devices are taken as the desired effects of the behaviour of the devices. It is shown that this account accommodates three archetypical meanings of functions.*

## KEYWORDS

function, different concepts of function, device descriptions, simplified device descriptions, functional modelling, design methodologies

## 1. INTRODUCTION

The concept of technical function is often taken as an important concept that is central to engineering tasks [11]. Yet, despite this broadly shared view, functions are by engineers currently not used with a single meaning. A recent survey by M.S. Erden and collaborators [13] lists 18 distinct engineering proposals to define functions, and acknowledges that the different meanings that in this way are attached to the term are not compatible with one another.

Given the importance and centrality of functions, it seems straightforward that engineers should aim at replacing this variety of meanings and at accepting eventually a single and well-defined concept of function. In the literature it is often noted that the current variety of meanings is hampering communication of functional descriptions between engineers (e.g., [12]), a problem that quickly disappears when engineers settle on a single meaning. Yet, engineers are again defying expectations. A debate towards establishing consensus about the meaning of the concept of function is by and large absent in the literature; contributions in which the variety of meanings is considered, seem rather to be aimed at distinguishing the different meanings, than at forging a choice (e.g., [11]). The different meanings of the concept of function thus seem to be accepted in engineering. They are taken as existing side by side, defining the remaining tasks of relating them and of developing the tools for translating functional descriptions using a first meaning into descriptions using a second.

The same tolerance can be found in research on engineering ontologies, a field that actually aims at establishing a common and well-founded conceptual framework for engineering. One can find in ontology efforts at defining a single meaning of the concept of function (e.g., [2, 21]). And there are ontological analyses that refrain from defining a single meaning and just formalise and relate the existing engineering meanings (e.g., [3]; see also [4] in this volume). And when a single meaning of function is defined in ontologies, this meaning still need not be meant for replacing the variety of meanings that are used in engineering. This single ontological meaning may also be used for merely relating and translating the different engineering meanings ([22, 24]; see also [29] in this volume). Such ontological defined meanings can even become accepted as additional proposals within engineering proper. The single ontological meaning defined in [21] is, for instance, listed as yet another proposal in the survey of Erden, et al. [13]).

The co-existence of different meanings of the term function is, as noted, hampering communication of functional descriptions in engineering; the ambivalences in responses to this co-existence may, in turn, hamper the resolution of this communication problem. Replacing the existing variety of meanings by a single one that is defined properly with ontological means, seems to deny the current practice in engineering to freely choose between the existing meanings. Translating functional descriptions in which functions are used with different meanings seems more effective, yet may be a route towards resolving the communication problem that is less attractive for those who still believe or hope that the current variety of meanings will in due time converge towards more unity [9, 13].

In this paper a clear response is developed to the coexistence of different meanings of functions, a response which eventually will enable researcher to define a well-defined route towards resolving problems with communicating functional descriptions. This response combines elements of attempts to establish a single meaning, with elements of attempts to accept and relate the current variety of available meanings. First I present results of an earlier analysis [30] of why engineers use the concept of function with different meanings. Second I define an account of functions that accommodates a number of those meanings. Briefly put, by this account a technical function of a device is the desired effect of the behaviour of that device. This desired effect can be described in different ways by engineers, depending on how they use the concept of function to relate the physical structure of the device with the goal for which the device is designed. The concept of technical function is in this picture an important and central concept in engineering, precisely because it has a variety of meanings.

## 2. SURVEY

An extensive and recent survey of the variety of meanings that is attached in engineering to functions is given by Erden, et al. [13]. Other contributions are [10, 12, 28]. Furthermore, there have been a number of special issues on functions with introductions [8, 11, 26], where the first two again survey the topic.

From the relatively academic perspective of philosophy of technology, these surveys are fairly liberal towards their subject matter. By proposing specific definitions of the concept of function, individual authors may be taken to at least implicitly claim some advantages of their definitions over rival others. But although such claims seem sometimes be made, as in the work of Y.-M. Deng [12] and B. Chandrasekaran [9], the general approach in the literature is one of tolerance. Authors do not attempt to single out one meaning by defending one definition and by arguing against the others. Authors may even advance different meanings simultaneously, e.g., [7, 10, 12], and explore the ways in which these meanings are related. The approach adopted is thus rather to accept the different meanings as existing side by side. Hopes towards more unity are phrased but also projected into the future, for instance, as conjectures that the different proposals are about to converge [9] or that they eventually may be partially integrated [13].

From a systematic perspective, surveys seem moreover not covering all existing work. The analysis presented in this paper is based on work done on technical functions as it can be found in the mentioned surveys. These surveys include important work originating in Europe, including that of V. Hubka and W.E. Eder [19, 20], and of Pahl and Beitz [25], but overlook work by, for instance, M.M. Andreasen and, as presented at the TMCE Symposia, Albert Albers [1]. (I here acknowledge fair criticism by some of the reviewers, who identified additional work on functions. My first impression is that extending the basis of my analysis to additional literature will add to the noted variety of meanings of functions as used in engineering. Possibly it will give evidence to other paradigmatic meanings than the three introduced in this paper, and possibly it may refine or adjust the account developed.)

## 3. ASSUMPTIONS AND METHOD

In this paper I aim at analysing the concept of function in a manner that combines attempts towards establishing a single meaning with attempts of accepting and relating the current variety of available meanings. Engineers use the different existing meanings of function side by side, and seem not to be inclined to stop doing this. For this reason I assume that an account of function should accommodate that this concept has a variety of meanings in engineering. Moreover, since engineers continue with using these different meanings even though accepting one meaning would have considerable advantages, an account faces an explanatory task. There are apparently advantages in engineering to use the term function with different meanings, and an account should make clear what these advantages are.

Secondly I assume that engineering still can benefit from an account of functions that brings unity in the variety of its meanings. Even when accepting that this term is for a good reason used ambiguously, managing this ambiguity will help lifting the engineering problem with communicating functional descriptions. Hence the second task to be taken up in developing an account of functions is to find a characterisation that captures all or at least a number of the engineering meanings.

It is not my aim to consider all meanings engineers attach to functions. Rather I focus on three archetypical meanings, which are given in Table 1.

**Table 1** Three archetypical meanings of function.

| |
|---|
| functions of devices as intended behaviour of those devices |
| functions of devices as the desired effects of the behaviour of the devices |
| functions of devices as the purposes for which the devices are designed |

The first meaning is advanced by, for instance, Robert Stone and Kristin Wood [27], and an example is "converting electrical energy into light and warmth" for the function of a lamp. In this meaning a function refers to behaviour of the device, and its description meets physical conservation laws (the energy of the electricity is supposed to equal the sum of the energies of the light and warmth). The second meaning is used in, for instance, Morten Lind [23], and the example may now be simply "converting electricity into light." Functions then still refer to behaviour but conservation laws are ignored in their descriptions: there is no claim that the lamp is 100% efficient when saying that its function is to convert electricity into light. The final meaning is advanced by, e.g., John S. Gero [14], and the purpose concerns, say, a state of affairs in the world that is to be realised with the device concerned: the lamp's function is, for instance, "illumination in the room."

The explanation of the co-existence of these three meanings is given in earlier work [30] and here presented in Section 4. In this explanation I assume that technical devices can be described by means of at least five key-concepts, drawing on a model given by David C. Brown and Lucienne Blessing [5]. Reasoning in terms of these five key-concepts provides engineers ways to relate the goals of clients to the physical structure of the devices by which these goals can be realised. Other descriptions of technical devices, like the ones set forward in design methodologies, can now be seen as simplifications of the elaborated five-key-concepts descriptions. Engineers can simplify these elaborated descriptions by cloaking parts thereof or by bypassing in them references to some of the key-concepts. In these simplifications engineers moreover adjust the meaning of the term function in such a way that the simplified descriptions remain useful for engineering reasoning about devices. This suggests explaining that engineers use the term function with different meanings because they employ different simplified descriptions of technical devices.

In Section 5 I take stock and attempt to subsume the different engineering meanings under one account of technical functions

## 4. DIFFERENT FUNCTIONS IN SIMPLIFIED DEVICE DESCRIPTIONS

### 4.1. Five-key-concepts for devices

Following a model for technical devices given by Brown and Blessing [5], one can give elaborated descriptions of devices and their uses by means of five key-concepts. Taking some distance from the particulars of Brown and Blessing's work, these concepts are *goal*, *action*, *function*, *behaviour* and *structure*, defined as in Table 2 ([30]; the definition of function is here rephrased without mentioning Brown and Blessing's concept of role). Function has now the second "desired effect of behaviour" meaning as is given in Table 1.

With these five key-concepts one can reason about devices, in particular from the goals of devices to their structure, and the other way round. This reasoning reveals a conceptual layering in which goals are linked to actions, actions to function and behaviour, and behaviour to structure, and vice versa (see Figure 1).

In designing, for instance, one reasons from a given goal for a device to a description of its required structure, as depicted in Figure 2. In this reasoning first

**Table 2** Definitions of the five key-concepts.

| | |
|---|---|
| goal | a state of affairs desired to be realised by an agent with the device |
| action | a deliberate manipulation the agent is to carry out with the device in order to achieve the device's goal |
| function | an effect the behaviour of the device has to have for letting the device's actions be successful |
| behaviour | the evolution of the physical state of the device |
| structure | the physical configuration of the device in its environment |

the goal is formulated (e.g., for a lamp it is illumination in a room). Then the actions that have to be carried out with the device for achieving the goal are planned (e.g., put the lamp in the room and connect it to the mains). Third, the required functions of the device have to be determined by fixing the effects the behaviour of the device has to have for letting the planned actions be successful (electricity should be converted into light). Four, the behaviour of the device should be fixed with these functions (the lamp should convert electricity into light and other, thermal, radiation). And finally the required structure should be fixed such that it can exhibit the identified behaviour (e.g., an old-fashioned glass bulb containing a tungsten wire in vacuum, etc.).

goals of the device
↓↑
actions with the device
↓↑
functions of the device
↓↑
behaviour of the device
↓↑
structure of the device

**Figure 1** Conceptual layering of five-key-concepts descriptions of devices.

The other way round, in analysing a device and its possible uses (see Figure 3), one can start with its actual structure and then determine its possible behaviour. This behaviour fixes series of effects and series of actions that may be carried out successfully on the basis of these effects. Finally, possible goals can be determined that can be achieved by these actions. (For the lamp, for instance, it may be analysed that it can not only illuminate a room but also heat it, and of course one can achieve also numerous other goals with the lamp, from "reasonable" ones such as scaring away burglars, to less "reasonable" ones like hitting and casting shadows.)

required goals of the device
↓
planned actions with the device
↓
required functions of the device
↓
required behaviour of the device
↓
required structure of the device

**Figure 2** Reasoning from a device's goal to its structure.

These descriptions of the reasoning from goals of devices to their structure, and *vice versa*, are clearly in a number of ways at odds with actual engineering reasoning. There are too simple-minded by suggesting that, say, design reasoning can be cut up in simple linear orderings of sequential steps from goals to actions, from actions to functions, etc., all the way down to the structure of devices. Design reasoning is generally considered to be iterative, which for instance would mean that the goal of a device that is being designed might change late in the reasoning process. Engineering reasoning about devices may thus be from a logical point of view display the linear and sequential ordering as depicted by Figures 2 and 3, but such ordering merely shows up in cleaned-up *post-hoc* reasoning; actual engineering reasoning is much more erratic.

possible goals of the device
↑
feasible actions with the device
↑
potential functions of the device
↑
possible behaviour of the device
↑
actual structure of the device

**Figure 3** Reasoning from the device's structure to its possible goals.

A second way in which these descriptions fail to capture actual engineering reasoning about devices, is by suggesting that engineers attach only one meaning to the term function: engineers attach more.

A final problem is that these descriptions are conceptually much too complicated as compared to actual engineering reasoning. The description of the lamp, as sketched above, may have been excessive for such a simple device, yet the point is more general: descriptions of devices or reasoning in designing is in engineering often presented as depending on less than five key-concepts. Typically the concept of action is not considered as a key-concept, and in the initial formulation of the currently much-discussed Functional Basis design methodology [27], the concept of behaviour is barely mentioned. Engineering descriptions of devices are thus conceptually speaking regularly simpler than the five-key-concepts descriptions.

I do not address the first point that actual engineering reasoning is iterative, but focus on the second and third points. By comparing the conceptually more simple engineering schemes of design methodology to the five-key-concepts descriptions of devices, I show how these five-key-concepts descriptions may be simplified, and how the meaning of the concept of function changes with these simplifications.

## 4.2. Function as a separating and bridging concept

Brown and Blessing [5], when giving their model for technical devices, actually acknowledged that the term function has more than one meaning in engineering. Following Chandrasekaran and Josephson [10], Brown and Blessing distinguished a *device-centric* meaning of function from an *environment-centric* meaning. In its device-centric meaning a function of a device (i.e., the effect the behaviour of the device has to have for letting the actions with the device be successful) is phrased in terms of the behaviour of the device, whereas in its environment-centric meaning a function of a device is phrased in terms of the effects this behaviour has on the environment of the device. For instance, in its device-centric meaning the function of a lamp is that a current through the tungsten wire leads to emitting light by the wire, whereas in its environment-centric meaning it is that light is falling on objects around the lamp. Both the device-centric and environment-centric meanings are still cases of the second “desired effect of behaviour” meaning as given in Table 1.

Accepting this double meaning in the model seems at first sight merely making the reasoning more complex since now we are dealing with six key-concepts

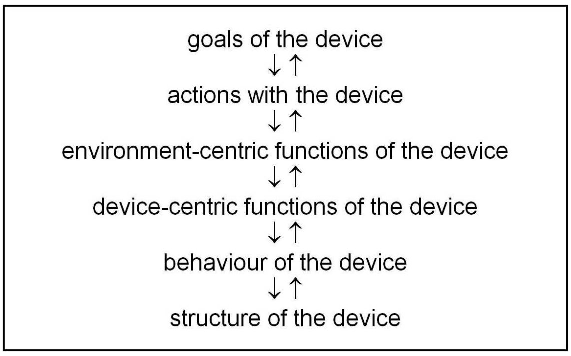


**Figure 4** Reasoning with two meanings of functions.

(see Figure 4). Yet, it can be shown that with this double meaning the model allows for simplifications of descriptions of devices. One can, for instance, “cloak” the physical parts of the descriptions by removing the references in the elaborated six-key-concepts descriptions to the devices’ structure, behaviour and device-centric functions. One then focuses in the descriptions on only the goals, the actions and the environment-centric functions (see Figure 5). Users can give such partial descriptions when they are not interested in the physics of technical devices. For instance, a user may just want to say that a lamp can be used to have a room illuminated. This can be expressed by saying that lamp has the (environment-centric) function to let light fall on objects around the lamp, and that by the actions of putting the lamp in the room and connecting it to the mains, the room with be lit.

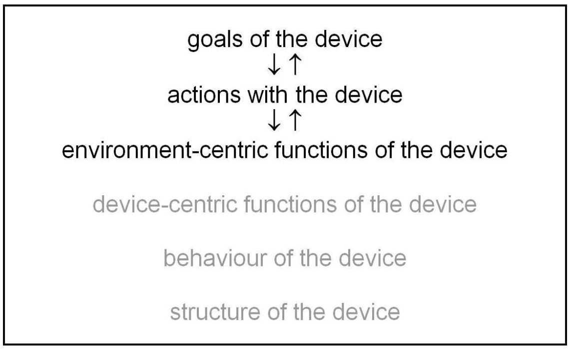


**Figure 5** Cloaking the physics in device reasoning.

By this double meaning one can also proceed in a reverse manner. One can “cloak” the teleological and action-theoretical parts by skipping references in the elaborated descriptions to the environment-centric functions, actions and goals (see Figure 6). One then focuses on the physical parts of descriptions of devices, as engineers may do when they are more interested in the technical aspects of the devices. The fact that the lamp can convert electricity in light is then explained in terms of the lamps physical structure and the behaviour it can exhibit by this structure.

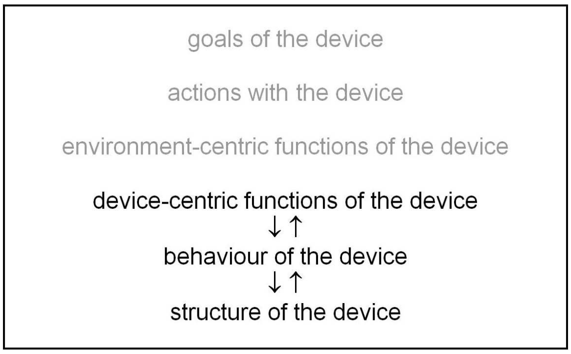


**Figure 6** Cloaking goals and actions in device reasoning.

The double meaning of the concept of function thus has advantages. By the ambiguity engineers and users can separate the elaborated five key-concepts descriptions of devices in a teleological/action-theoretical part about goals, actions and environment-centric functions, and a physical part about device-centric functions, behaviour and structure. Moreover, by its ambiguity the concept of functions also provides a bridge between these two parts: by reasoning from environment-centric functions to device-centric functions, and *vice versa*, the parts get reconnected (see [31] for a more extensive analysis of this separating and bridging of cloaked device descriptions by means of the concept of function).

## 4.3. Function as a bypassing concept

By comparing the five-key-concepts descriptions of devices with the reasoning schemes that are proposed in design methodology, one can also argue that the different engineering meanings of the concept of function are advantageous for simplifying the five-key-concepts descriptions by "bypassing" one or more of those key-concepts.

Consider, first, the *Functional Basis* (FB) design methodology proposed by Stone and Wood [27]. In this methodology, functions are taken or represented as operations on flows of materials, energies and signals, in line with the work by Pahl and Beitz [25]. By the FB methodology designing starts by deriving from customer needs a description of the overall product function of the device that is to be designed.

This product function is captured by a verb-noun expression and represented as a black-boxed operation on flows of materials, energies and signals. The product function is then decomposed into a network of basic functions as defined by libraries of basic operations and basic flows [17]. And with this network of basic functions design solutions are searched and composed.

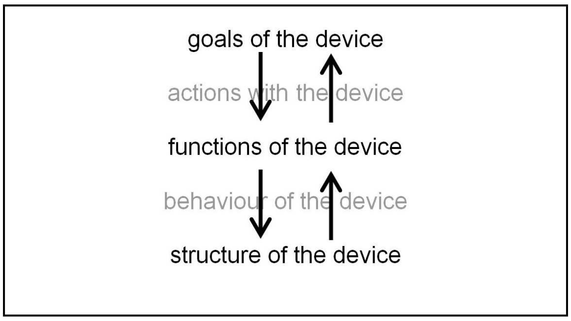


**Figure 7** Bypassing actions and behaviour in FB reasoning about devices.

Considered relative to five-key-concepts descriptions of devices, designing engineers reason in FB in one step from goals to functions and then in one step from functions to structure, bypassing thus the actions users execute with the device and the behaviour devices exhibit. Function is in FB used in the first "intended behaviour" meaning as given in Table 1. And by using functions in this meaning, one could argue that in FB the concept of behaviour is implicitly still employed in the descriptions of devices: in FB reasoning the concept of function, because it is used in its "intended behaviour" meaning, refers both to the behaviour for which devices are designed and to the effects of that behaviour by which those devices contribute to the realisation of the goals of the devices. This bypassing of the key-concepts of action and behaviour can be depicted as in Figure 7.

Consider, second the MFM (*Multilevel Flow Modelling*) approach by Lind [23] in which functions of in particular industrial plants are understood as representing "the roles the designer intended a system should have in the achievement of the goals of the systems(s) of which it is a part". In this approach functions are represented by sets of mass, energy, activity and information flows, and a distinction is made between functions of the plant itself, represented by mass and energy flows, and functions of operators or control systems of the plant, represented by activity and information flows.

The key-concepts in an MFM model of a plant are goal, function, behaviour and structure. By including functions of operators, the actions of those operators are considered in MFM. But those are actions of the operators and should not be confused with the actions of the agents who are using the plant. The relevant example discussed by Lind is a power plant boiler. This plant has the main goal of generating electricity, meaning that the agents who use the plant are those who use the electricity. Actions of such using agents are ignored in MFM models. An MFM model contains the goals for the plant, which consists of its main goal and the goals of the structural parts of the plant. These goals of the structural parts are achieved by the functions of these parts, which may be functions of the parts, or functions of operators/controller systems. In [23] behavioural descriptions are announced as being also elements of MFM models, but they are not actually included.

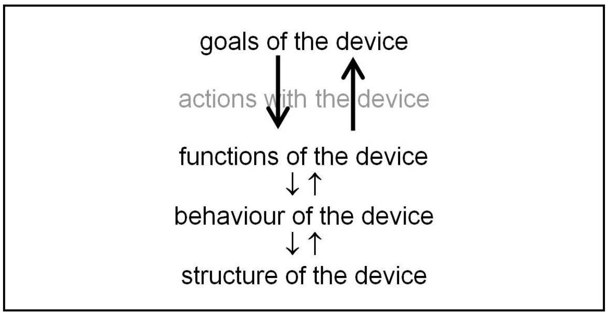


**Figure 8** Bypassing actions in MFM reasoning about devices.

Considered relative to the five-key-concepts descriptions of devices, MFM models bypass the key concept of action (by users), as depicted in Figure 8. Behavioural descriptions are, as said, not yet included in the models but meant to be included. Functions are in MFM thus employed to relate goals of industrial plants with their behaviour, and have the second (environment-centric) meaning of "desired effect of behaviour" of devices, as given in Table 1. By bypassing only actions but not behaviour, one can now argue that it makes sense that this "desired effect of behaviour" meaning is adopted in MFM, and not the other two meanings given in Table 1. If the first "intended behaviour" meaning would have been used, reasoning from function to behaviour becomes the trivial step of maintaining that behaviour of the device should include the function. If the third "purpose" meaning of function would have been chosen, reasoning from goals to function becomes trivial.

A final example is the FBS (*Function-Behaviour-Structure*) design model of Gero [14]. In this model designing is in its barest form an activity in which functions are transformed into design descriptions of devices that can perform these functions. These functions originate from clients, and the design descriptions determine how the devices can be made. The functions are transformed into design descriptions via elementary design steps in which also behaviour of the devices and their structure are considered. It may seem that in the FBS model designers fully ignore the goals and actions of devices. Yet, Gero defines functions as the "design intentions or purposes" related to devices [16]. If these design intentions or purposes are the purposes users have with the device, the distinction between the key-concepts of goal and function has disappeared.

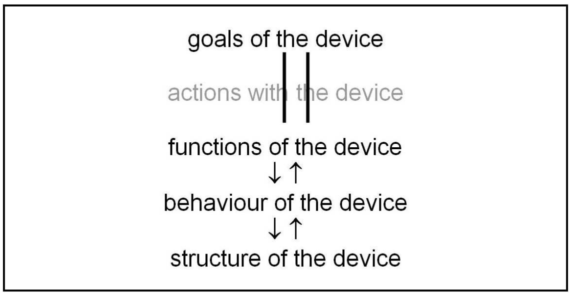


**Figure 9** Bypassing actions and equating goals and functions in FBS reasoning about devices; the vertical lines represent an "is equal" sign "=".

The reasoning then proceeds from functions in the "purpose" meaning straight to behaviour, and then to structure, leading to descriptions in which the actions of users with devices are bypassed, as in Figure 9. If, however, design intentions or purposes refer to the effects the device should have in use, functions are used in the (environment-centric) meaning of "desired effects of behaviour". In this second case the goals of users and their actions are cloaked in the design reasoning, and the reasoning leads to physical descriptions as depicted in Figure 6, linking functions to behaviour and structure. Gero's writing on the FBS model offers evidence that functions can have both meanings: the function of a window is, for instance, described as "providing view", which refers more to intentional goals of using agents, and "controlling noise", which refers more to the effects of behaviour of the window ([15], section 4).

If Gero indeed uses function in the "purpose" meaning, then one could argue that in FBS descriptions of devices the key-concept of goal is still employed, because FBS functions of devices and the goals of those devices are one and the same concept.

These three examples show that design methodologies simplify the elaborated five-key-concepts descriptions of devices by bypassing one or more of the key concepts. Moreover, design methodologies simplify these elaborated descriptions in different ways, depending on which specific key-concepts are bypassed. The three examples also show that the meaning by which the concept of function is used in the simplified description depends on the simplification at hand: if the concepts of action and behaviour are bypassed (as in FB), then it makes sense to opt for the "intended behaviour" meaning; if only the concept of action is bypassed (as in MFM), then one better opt for the "desired effect of behaviour" meaning; and if actions are bypassed and the key-concepts of goal and of function are taken as one as the same, one ends up with attaching the "purpose" meaning to the concept of function.

Hence, the conclusion as given in [30] is that one can explain the co-existence in engineering of at least the three archetypical meanings of function as given in Table 1, by means of the co-existence of different ways to simplify descriptions of technical devices: there are different ways in which engineers can simplify the elaborated five-key-concepts descriptions of technical devices, and these simplifications remain useful descriptions of engineers because they can use the concept of function in more than one meaning.

## 5. ONE ACCOUNT

Having observed that the concept of function is currently used by engineers with a variety of meanings, and having explained why engineers do so, the question remains how one can understand functions in engineering. Arguing that the concept of function has still actually one precise meaning becomes somewhat impossible without entering into conflict with useful engineering practices. One may claim that functions are in all engineering modelling used to reason from goals of devices to the physical structure of these devices, but more agreement about the concept of function seems not to exist in engineering.

The alternative approach to accept that engineers attach a variety of meanings to functions seems inevitable but has the disadvantage that it leads eventually to the position that there are *different* concepts of functions being used in engineering. The suggestion that there is some unity available among these concepts is then an idle one. The survey by Erden et al. [13] shows that engineers use 18 different concepts, which can better be kept apart by giving them different names, like function$_1$, function$_2$, and so on.

Still, the suggestion that there is some unity between the different meanings is given. Engineers refer to these meanings with the single term "function", and hopes that these meanings eventually converge or are integrated are expressed. In the remainder of this paper I will take up this suggestion and attempt to formulate an account of functions that advances one overall meaning of the term that is broad enough to include the other meanings. It may seem that I eventually defend one meaning of function and reject the others. This is however not the case. What I aim at is arguing that the "desired effect of behaviour" meaning can be interpreted in a broad sense such that the other meanings become instances of it. In my attempt I focus on the three archetypical meanings of function as given in Table 1.

### 5.1. A broad sense of desired effects

By the account that I propose a function of a device refers always to a desired effect of behaviour of the device. The other two archetypical meanings of functions as given in Table 1, are special cases of this general "desired effect of behaviour" meaning, or so I will have to argue.

I start by spelling out in more detail what I mean with desired effects of the behaviour of devices. For this I need some basic terminology, which I adopt from [6]. Let a state of affairs in the world consists in a number of objects with properties and relations between the objects and their properties. States of affairs are static. Dynamics in the world is introduced by sequences of states of affairs: "[a]n event is a single chance, involving a pair of [systematically different] states of affairs; a process is a more complex series of events." ([6], p. 25) For allowing also for events and processes that stabilise a specific state of affairs, I assume that states of affairs in events and processes may also be similar to one another.

*Behaviour* of a device may now be taken as events and processes involving states of affairs that necessarily consist in the device and/or its properties and that possibly consist in objects and their properties that are physically interacting with the device. Behaviour of the lamp, for instance, is a process that concerns the lamp, incoming electricity, and outgoing light and thermal radiation.

Behaviour may be represented by, for instance, a verb-noun expression or by evolving state variables of the device and the objects that are interacting with it. If behaviour can be taken as a process, it can also be represented by operations of flows, as advanced by Pahl and Beitz [25] and Stone and Wood [27].

Behaviour is a physical phenomenon and meets the conservation laws as given by physics. When behaviour can be taken as an event, the initial and the final states of affairs should contain equal amounts of energy, matter, charge, and so on. And when behaviour can be taken as a process, the input and output flows should again contain equal amounts of energy, matter, etc. For the behaviour of the lamp the incoming electricity and the outgoing light and radiation contain equal amounts of energy.

*Effects of behaviour* of a device are now events and processes that are the result of behaviour of the device. These events or processes may consist in states of affairs consisting in the device itself and/or its properties (as in device-centric functions as introduced by Chandrasekaran and Josephson [10], in states of affairs consisting in the environment of the device and/or the environment's properties (as in environment-centric functions), or in states of affairs that are combinations thereof.

Effects of behaviour may also be represented by verb-noun expression, by evolving state variables or, in the case of processes, by operations on flows. But now the description need not meet physical conservation laws. The behaviour itself meets those laws, but the effects may be described in a manner that ignores conservation laws. The behaviour of the lamps on the Eiffel Tower, for instance, meet conservation laws, but their effect may be describes as that flipping a single switch leads to the illumination of the tower, where the flipping involves a small amount of energy input, and the lighting of the Eiffel Tower involves enormous amounts of energy output.

*Desired effects of behaviour* of a device are effects of the device that are desired by an agent. This agent is in the proposed account a designer or an analyst of the device, and not a user of the device. Designers and analysts determine which effects behaviour of devices should have in order that the device can play its role in the actions with the device and thus can play its role in realising the goal of the device.

Desired effects of behaviour of a device are not necessarily the goals of the device (such goals may be states of affairs, events or processes). Consider, for instance, the clutch of a car. The desired effect of the clutch's behaviour is that the car's engine stops to drive the wheels when the clutch is disengaged, whereas its goal is to allow the user to shift gears.

Users are, on the other hand, not necessarily agents that desire effects of the behaviour of devices. A user of a device clearly has desires concerning the device, and they are about the goal of the device that the user can realise by carrying out the device's actions. Yet a user of the device need not reason about how this goal is realised. As a user he or she may just carry out the actions with the device and then expect that the goal of the device will be realised [18]. A user of a car may know that the clutch is to be used for the goal of shifting gears, and that the action involved in realising this goal consists in pressing the left-most pedal. And a technologically uninterested user may leave it at that, lacking thus the knowledge what the effects are of the behaviour of the clutch as desired by the designer. (A user may also not leave it at that, and reason about the effects of the behaviour of clutches; in the account such a user is an analyst of the device).

## 5.2. Intended behaviour and purposes

Let functions of devices thus refer to the desired effects of behaviour of the devices. The "intended behaviour" meaning as given in Table 1 can now be accommodated as descriptions of such functions that meet two additional constraints: first, the desired effects of the behaviour of devices are described in terms of the behaviour of the devices, and, second, these descriptions explicitly meet physical conservation laws. The first constraint limits descriptions of functions to device-centric descriptions in terms of events and processes that concern only the devices and their properties. The second constraint requires that if behaviour is described as an event, the states of affairs making up the event, should be similar in terms of energy value, matter, charge, and so on. If behaviour is described by a process, it is a process concerning events for the device, and the input and output states of affairs, should again be similar in terms of energy value, matter, charge, and so on.

These additional constraints need not be adopted in the account, but they can be adopted, say for emphasising the relation between the concepts of function and behaviour, as is useful in the Functional Basis methodology.

The "desired effect of behaviour" meaning as given in Table 1 is trivially accommodated in the account as proposed, so let us consider the "purpose" meaning.

In this third meaning as given in Table 1 functions of devices are the purposes for which the devices are designed. In the proposed account these purposes are identified as the effects of the behaviour of the devices *as desired by their designers*. Typically functions in the purpose meaning are referring to states of affairs to be realised by the device, and they may coincide with the goals of the devices but do not do so in general: for the lamp the purpose function may be illumination in a room, which is also the goal of the lamp; and for the clutch, the purpose function may be to stop the car's engine to drive the wheels when the clutch is disengaged, which, as argued above, does not correspond to the goal of the clutch. In both cases, the states of affairs referred to by the purpose meaning are states of affairs for which designers have designed the devices and that should be the result of the behaviour of the devices. Hence functions in the "purpose" meaning can then be taken as instances of the "desired effect of behaviour" meaning. The same position is possible when functions in the purpose meaning refer to events or processes: also these events and processes can be taken as the effects of the behaviour of the devices that are desired by their designers.

In the account functions may thus also be described as purposes for which devices are designed, and this may be useful when one want to simply descriptions of devices by taking their functions and goals as similar, as is done in the FBS methodology. Functions described as purposes are then typically environment-centric descriptions of the desired effects of behaviour of devices. Yet, in the account functions and goals of devices are not one and the same concept; even when functions are described as purposes, they are states of affairs, events or processes desired by designers or analysts, whereas goals of devices are states of affairs, events or processes desired by users.

## 6. RESULTS AND DISCUSSION

Considering the results so far, the following picture emerges. Engineers use the term function with a variety of meanings, and engineers accept this ambiguity because they have good reasons to use functions with a variety of meanings. These reasons have to do with descriptions of technical devices. Engineers can give detailed descriptions of such devices, and engineers can give different simplifications of such descriptions provided that they can adjust the meaning of the term function. Yet this adjustment of the meaning of function in engineering descriptions of devices need not lead to the conclusion that the concept of function is one without an overall unity: the account of functions that I proposed in the previous section advances one overall meaning and accommodates at least three archetypical meanings attached by engineers to functions. Hence, one can both accept the variety of meanings for functions and still maintain that this concept has one overall general meaning. The results thus show that one can approach functions in engineering in a way that combines elements of attempts to replace the current variety of meanings with a single meaning, and of responses in which the variety of meanings is tolerantly accepted as existing side by side.

If this account of functions is acceptable, one can envisage two ways in which the analysis of the concept of function in engineering can proceed. I have argued that the three archetypical meanings as given in Table 1, fit the account. Further analysis may now reveal whether other engineering meanings of functions fit the account as well, taking the survey by Erden, et al. [13] as a first but source of those other meanings, and extending the scope to other work on functions as well. This analysis may lead to positive results; if it does not, one is again faced with the issue how to approach the remaining variety of meanings. One can reject the meanings that do not fit the account, effectively replacing the current variety of meanings with only those meanings that are accommodated by the account. Or one can still accept the meanings that do not fit the account, which would bring us back to the issue of the unity of the concept of function. Future research should yield whether we indeed will be faced by this issue, but now the option of replacing the current variety of meanings with only those accommodated by the account is less unattractive: the account accommodates at least the three archetypical meanings as given in Table 1, and allows engineers to still simplify descriptions of devices as described in Section 4.

Turning now to the communication problem for functional descriptions, the proposed account suggests a resolution that consists of laying down a single meaning of function and of developing translation rules for functional descriptions using different archetypical meanings. That single meaning – the desired effect of behaviour of a device – can be fixed rigorously, say by ontological means. And a first approximation of the translation rules can be determined with Table 1. For instance, functional descriptions using functions in the "intended behaviour" meaning can without complication be taken as functional descriptions using functions in the “desired effect” or “purpose” meanings.

The resulting translated functional descriptions are typically very detailed relative to other functional descriptions using function in the desired effect or purpose meanings (a functional description of a lamp using the latter meanings, may consist of the short description that the lamp is for illuminating a room, whereas in the translated description its desired effect/purpose function is to transform electricity to light and thermal radiation) but this does not make the translated functional descriptions incorrect. Giving rules for the reverse translation becomes with Table 1 similar to giving rules for designing itself. A functional description using functions in the “desired effect” or “purpose” meanings, is silent about the details of the behaviour that can realise the given effect or purpose. Translating such a description into one using function in the “intended behaviour” meaning implies adding that detail, which is one of the tasks in designing.

## 7. CONCLUSIONS

In this paper I first presented an explanation of why engineers use the concept of function with different meanings [30]. This explanation focused on descriptions of technical devices. Engineers can give such descriptions by using the five key-concepts of goal, action, function, behaviour and structure of devices [5]. And engineers can simplify these descriptions by cloaking parts thereof or by bypassing in them references to some of the five key-concepts. These simplifications are made possible because engineers can adjust the precise meaning attached to the term function. Second I proposed an account of functions that accommodates at least three archetypical meanings of function. In this account functions are taken as the desired effects of the behaviour of devices, and it was shown that this account accommodates also the meanings of intended behaviour of devices, and of purposes for which devices are designed. With the account one can accept that engineers use the concept of function with different meanings and still capture its overall unity.

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